

## Deserts in a Changing Climate: Impacts

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## CONTENTS

<b>Executive Summary</b>	161	<b>3.4. Impacts of Climate Change</b>	165
<b>3.1. Introduction</b>	162	3.4.1. Higher Temperature	165
<b>3.2. Climate and Biology</b>	162	3.4.2. Rainfall	165
3.2.1. Definition and Extent	162	3.4.3. Runoff and Ephemeral Waters	166
3.2.2. Biological Productivity	163	3.4.4. Desert Locusts	166
3.2.3. Desert Biodiversity	163	3.4.5. ENSO and Related Issues	167
<b>3.3. Ecosystem Variables</b>	163	<b>3.5. Biogeographical Shifts</b>	167
3.3.1. Temperature	163	<b>3.6. Mitigation</b>	167
3.3.2. Rain and Soil Moisture	163	<b>3.7. Future Needs</b>	167
3.3.2.1. Factors in Moisture Budget	163	<b>Acknowledgments</b>	167
3.3.2.2. Pulse System	164	<b>References</b>	167
3.3.3. Wind	164		
3.3.4. Fogs	164		
3.3.5. Nutrient Cycles	164		

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## EXECUTIVE SUMMARY

Deserts are an environmental extreme. The biota in deserts are at the limit of conditions that allow growth and survival and show very specialized adaptations to aridity and heat. The biomass of plants and animals is low; nevertheless, deserts have a significant species richness and a high endemism. The following statements regarding climate change can be made with certainty:

- Most deserts are likely to become even more extreme if climate changes as projected by current scenarios; most desert regions are expected to become hotter and most will probably not become significantly wetter (Medium Confidence).
- If changes in the frequency or intensity of the rainfall events occur, they are likely to cause changes in the flora and fauna. Higher atmospheric CO<sub>2</sub> concentrations and more intense rainfall events may lead to the opportunity for greater invasion of desert systems, particularly by C<sub>3</sub> plants. More frequent large pulses of rain will allow ephemeral organisms to reproduce more often. Any reduction in the intensity of the rainfall, however, could also be detrimental to this set of organisms due to false starts in their life cycles (Medium Confidence).

- In a few places (e.g., central Australia) conditions may improve, but any net change in rainfall—thus the vegetation—will depend largely on the human management of these regions (Low Confidence).
- Opportunities to mitigate greenhouse gas emissions in desert regions are few (High Confidence).

Human-induced desertification has the potential to counteract any ameliorating effect of climate change on most deserts unless appropriate management actions are taken.

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### 3.1. Introduction

This chapter describes deserts and the main processes that dominate extreme desert environments. It then discusses how these processes might be affected by climate change. Variability in different deserts is described, and the likely impacts on specific areas are explored. The chapter concentrates on the hottest and driest land types and excludes extreme-cold deserts of polar regions.

### 3.2. Climate and Biology

#### 3.2.1. Definition and Extent

Deserts are characterized by low rainfall that is highly variable both intra- and interannually. Desert air is very dry, and incoming solar and outgoing terrestrial radiation are intense. Large daily temperature fluctuations occur (ca. 30°C), and potential evapotranspiration is high. There is high spatial and temporal variability in desert biota, driven largely by water availability (Noy Meir, 1985).

There are many definitions of deserts, but the common point is that water (or the lack of it) is the dominant factor controlling ecosystem processes. A common definition classifies ecosystems with an annual rainfall of <250 mm as arid and <100 mm as extremely arid (Noy Meir, 1973; Walter, 1985). Both are commonly referred to as deserts, but this chapter concentrates

on the extremely arid regions; Chapter 2 deals with most aspects of arid and semi-arid regions. The permanent biota in extremely arid regions have specialized adaptations to cope with the harsh environment—sometimes obtaining their moisture from fog or dew. There also are ephemeral biota that migrate into desert regions or become active from drought-resistant seeds or dormant life stages, to take advantage of the rare rainfall events. Thus, extreme deserts have very distinctive characteristics.

Desert environments arise in several circumstances. Most deserts occur between 20° and 40° latitude, where persistent high-pressure cells bring dry air to the Earth's surface (see Figure 2-2 in Chapter 2). However, the climate depends on the precise balance between this air mass and topography, continentality, and sea currents (Evenari, 1985a). Some deserts are in the rain shadows of major mountain ranges (e.g., the Atacama desert of South America; see also Chapter 5). Others are a great distance from a source of oceanic moisture or are more-or-less continuously swept by winds that have traveled a great distance over land (e.g., the central Asian deserts).

Approximately 30% of the globe's land surface is desert or semi-desert, with almost 5% receiving less than 70 mm annual rainfall, 11% less than 100 mm, and 18% less than 120 mm (Shmida, 1985; Le Houerou, 1992). Some of the extremely arid deserts are shown in Figure 3-1. Human population estimates for the extremely arid regions are not available; however, for regions classified as drylands (i.e., <75 growth days per year)

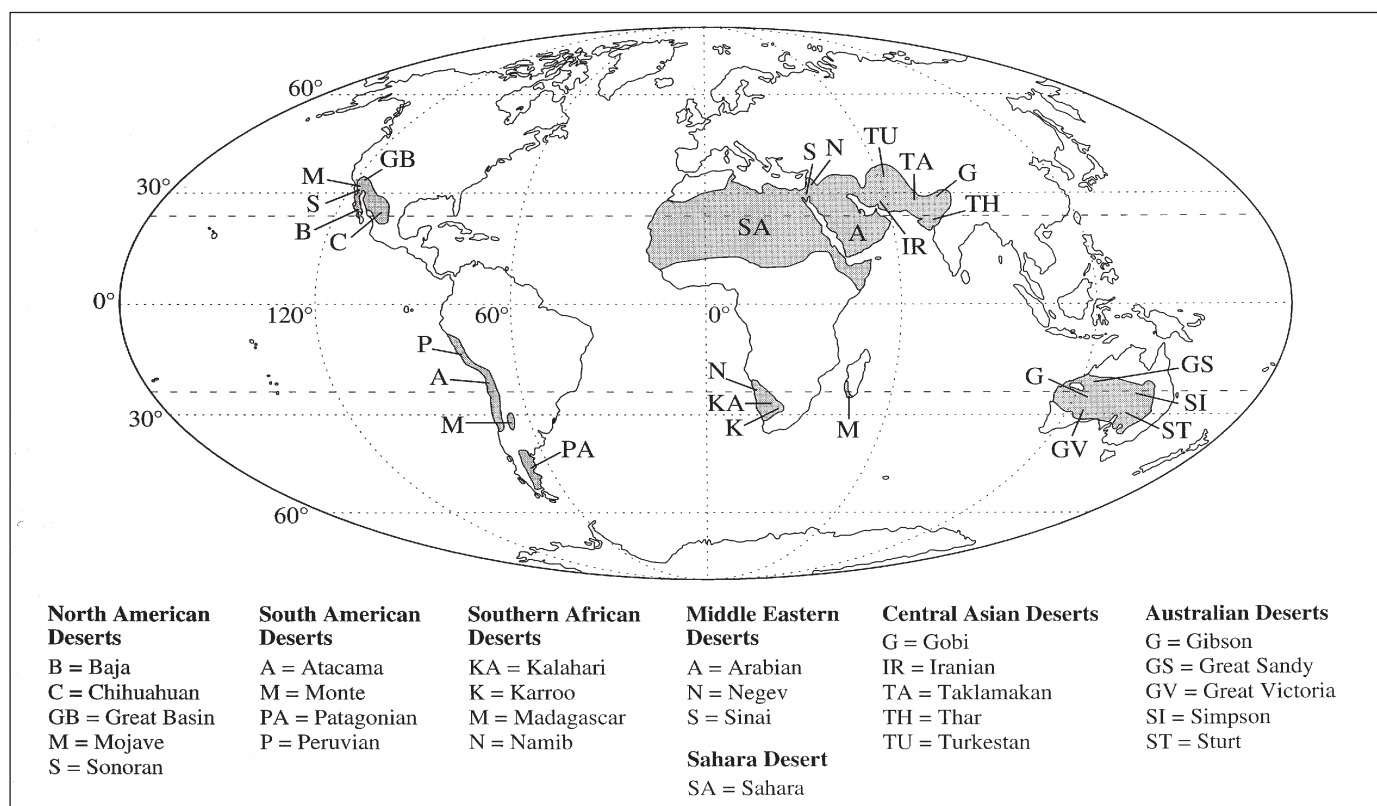


Figure 3-1: Deserts of the world.

it is over 800 million people (World Resources Institute, 1988–89). Many of these people will be affected by phenomena described in this chapter.

### 3.2.2. Biological Productivity

Average aboveground net primary productivity in areas with annual precipitation of <250 mm varies from almost 0 to about 2000 kg/ha/yr (Evenari *et al.*, 1971; Noy Meir, 1973; Hadley and Szarek, 1981; Webb *et al.*, 1983; Le Houerou, 1984). Most productivity estimates are for aboveground vegetation only; there is very little information on belowground plant productivity. Root to shoot ratios differ greatly among desert life forms (Noy Meir, 1973). Ephemeral species often have relatively small root systems (root:shoot < 0.5), whereas some perennials have large belowground storage systems with root:shoot ratios as high as 20. Productivity is directly related to rainfall, often by a simple linear function. Alternatively, it can be expressed as a close relationship with actual evapotranspiration because actual evapotranspiration is closely related to rainfall (Branson *et al.*, 1981). Estimates of water-use efficiency by desert plants vary from 0.3 to 2.0 mg dry matter produced per gram of water transpired, with a threshold of 25 to 170 mm of annual rainfall to sustain any vegetation at all (Noy Meir, 1973; Webb *et al.*, 1978).

### 3.2.3. Desert Biodiversity

Although deserts are not as diverse as some biomes, they have significant diversity—with many groups of organisms and often a high degree of endemism (Le Houerou, 1992). Taxa that are diverse relative to other biomes include predatory arthropods, ants, termites, snakes, lizards, migratory birds, succulents, and annual plants (McGinnies *et al.*, 1968; Huenneke and Noble, 1995). There is substantial variation in the richness of particular taxa among the deserts of different continental areas (Evenari, 1985b; Huenneke and Noble, 1995). Desert biota are unusual in the frequency with which particular morphological or physiological adaptations have evolved independently in different taxonomic groups (Cloudsley-Thompson, 1993). For example, many animals and plants have thick skins or cuticles to reduce water loss; other have hairs or spines to reflect radiation.

Biodiversity—measured as the number of species (i.e., species richness)—is moderately high in semi-arid regions and declines with increasing aridity for most taxa (Shmida, 1985; Pianka and Schall, 1981; Currie, 1991; O'Brien, 1993). For example, Aronson and Shmida (1992) found that plant species richness fell linearly from 116 species at a site with 280 mm mean annual rainfall to 15 species at a site with about 30 mm mean annual rainfall. The number of life forms (e.g., annual grasses, small shrubs) declined with increasing aridity, and only chamaephytes (low-growing perennial plants with buds just above the soil surface; e.g., *Salsola tetrandra*) persisted at the driest sites in all years. In addition, they found very little

fluctuation of species richness with variability in annual rainfall at the driest site.

Correlative studies show that the diversity and density of some animal groups are related to vegetation productivity gradients, precipitation, and potential and actual evapotranspiration (Clark, 1980; Maurer, 1985; Owen, 1988; Currie, 1991; Hoffman *et al.*, 1994; Specht and Specht, 1994). However, the links are complex—depending on the taxonomic group, seasonality of precipitation, frequency of droughts, and the scale at which diversity and density are measured. Thus, changes in animal populations in response to changes in climate are very difficult to predict.

## 3.3. Ecosystem Variables

### 3.3.1. Temperature

The hottest deserts of the world (e.g., central Sahara, Namib) have average monthly temperatures above 30°C during the warmest months, with extremes above 50°C. The diurnal range often is very high, with nights as cold as 10°C. High insolation loads mean that soil surface temperatures often rise to more than 80°C (Cloudsley-Thompson, 1977).

Some high continental deserts have extremely cold winters; e.g., the Chihuahuan Desert in North America has average monthly minimum temperatures below freezing (MacMahon and Wagner, 1985). Cold conditions prevent effective growth of plants in winter; however, snow or moisture often accumulates and can contribute to growth in the warmer months.

### 3.3.2. Rain and Soil Moisture

#### 3.3.2.1. Factors in Moisture Budget

Precipitation, soils, and temperature all contribute to the nature of desert ecosystems. Vegetation is largely a function of rainfall modified by soil type (in particular, the coarseness of the soil; Bertiller *et al.*, 1995) because these two factors determine potential soil moisture and water-holding capacity. Higher temperatures usually imply higher vapor-pressure deficits (evaporative demands) and thus higher evaporation and transpiration losses.

The availability of moisture at and near the soil surface is critical for the activity of desert organisms. The water available to plants is dependent on the balance between input from precipitation and losses from direct evaporation from the soil surface, transpiration through the leaf-root systems of plants, and drainage below the root zone. Thus, the effectiveness of a given amount of rain is dependent on how far it infiltrates below the surface; greater penetration reduces evaporative losses. More-intense rainfall events tend to penetrate less and create more runoff than less-intense events. In contrast to most other arid ecosystems, the sandy soils of extreme deserts

support higher plant biomass than do clay soils (Walter, 1985) because water penetrates deeper in coarser soils.

To a large degree, water loss due to transpiration is an unavoidable byproduct of the necessity for plants to take up  $\text{CO}_2$  from the atmosphere through stomata. Various adaptations have developed to limit this loss (Ehleringer and Monson, 1993). Most  $\text{C}_3$  species have a common metabolism but can vary enormously in leaf structure, leaf protection, stomatal density, and control over stomatal activity. For example, many species close their stomata during the hottest part of the day to avoid the highest rates of water loss. Some  $\text{C}_4$  species have a special leaf anatomy and metabolism that allows them to concentrate  $\text{CO}_2$  within the leaf and thus reduce water loss. Several major groups of plants (mostly succulents) have CAM species, in which most gas exchange is limited to the cooler nighttime hours.

These mechanisms are all of particular importance in desert communities, where water is usually limiting while light and  $\text{CO}_2$  are usually in excess. Increased concentrations of atmospheric  $\text{CO}_2$  will alter the relative effectiveness of these mechanisms and thus the balance of plant communities. It is expected that this will favor  $\text{C}_3$  species over  $\text{C}_4$  and CAM species (Skiles and Hanson, 1994), which could make desert communities more subject to invasion and increased dominance by  $\text{C}_3$  species.

### 3.3.2.2. Pulse System

Biological activity in most ecosystems is controlled by the availability of light, water, and nutrients. Complex interactions and feedbacks have developed that govern the growth and development of organisms in these systems. In contrast, desert ecosystems are dominated by rainfall events. Rainfall is infrequent, usually highly unpredictable, and often provides moist conditions for only a short period. Deserts have been described as pulse-driven ecosystems (Noy Meir, 1973). This means that the response of desert ecosystems to climate change may be different than that of other systems, where more complex feedbacks and interactions have developed.

Most desert organisms are adapted to one of two survival mechanisms (see Noy Meir, 1973). Some survive in a dormant state between rainfall pulses and take quick advantage of the brief respites. Typical examples are the ephemeral plants, but certain species of crustacea, molluscs, and frogs use similar strategies (Williams and Calaby, 1985). Other organisms—such as perennial plants, reptiles, and some mammals—persist through the dry conditions because they have extremely efficient water and energy conservation strategies (Williams and Calaby, 1985). Some smaller plants and animals are able to persist on the moisture settling as dew or fog (Louw and Seely, 1982).

Climatic changes that increase the frequency of pulses will favor the pulse-adapted (i.e., ephemeral) species if the duration of favorable conditions is not shortened. In the long term, more-frequent pulses of ephemerals could affect the long-lived perennial species either by directly competing for resources or

indirectly affecting local fire frequency and grazing intensity (Skarpe, 1992).

If, under climate change, the duration of periods of moist conditions becomes shorter or more variable, the pulse-adapted species may be disadvantaged. They will be triggered into responding more frequently but will often fail to complete their life cycle in the shorter moist periods (Frasier *et al.*, 1985, 1987). For example, ephemeral plants could be triggered into germinating but not have time to set seeds before drying out, thus depleting their seed bank.

### 3.3.3. Wind

Windiness varies from desert to desert, but in general windiness is not significantly different than in nondeserts except that there is little vegetation to moderate the wind near the ground surface. This creates soil instability and is the major factor creating and shaping dune systems and extending desert boundaries (Alwelaie *et al.*, 1993). Some organisms are adapted to feed on the accumulation of organic matter on the slip faces of dunes (Louw and Seely, 1982).

### 3.3.4. Fogs

Fog and dew can each contribute 30 mm or more of moisture per year. Dew can form on more than half the nights of a year in some deserts (Seely, 1979). Thus, fog and dew are an important and relatively reliable source of water for plants and animals alike (e.g., Namib beetles and lizards; Louw and Seely, 1982). In some of the driest coastal deserts (e.g., Atacama or Peruvian deserts), fogs are particularly frequent and provide the majority if not all of the moisture in most years (Rauh, 1985). Alwelaie *et al.* (1993) have suggested that the shrub-dominated vegetation in a desert island in the Red Sea depends on fog for its water supply.

### 3.3.5. Nutrient Cycles

The main sources of nitrogen in deserts are N-fixing organisms on the soil surface such as lichens, cyanobacteria, moss, and fungi. Atmospheric deposition is an important source in some areas. Nitrogen fixation inputs in arid regions of the United States are 25 to 40 kg N/ha/yr (West and Skujins, 1977; Rundel *et al.*, 1982), whereas atmospheric deposition is estimated to be 3 kg N/ha/yr (Peterjohn and Schlesinger, 1990). Assimilation of nitrogen from fog is sometimes considered to be a significant source of N, but Evans and Ehleringer (1994) found that this is not the case in the fog zones of the Atacama Desert.

Rates of decomposition in deserts are slow because warm and moist conditions that favor decomposition are rare and volatilization of N can be high due to low vegetation cover and high evaporation. Thus, many desert systems are N-limited. Some studies have shown that decomposition rates are correlated with rainfall



in arid regions (Santos *et al.*, 1984), but others (Whitford *et al.*, 1986) have failed to find a correlation. Steinberger and Shmida (1984) conclude that along a rainfall gradient of 300 mm to 25 mm there is no correlation between decomposition and rainfall and that most decomposition in very dry regions arises from mechanical rather than biotic processes.

Soil nitrogen is unevenly distributed in arid environments and is usually higher in surface soil and beneath larger plants or shrubs than in bare areas (Charley and West, 1977). Most nitrogen fixation occurs near the soil surface, and species that take up most of their water from the surface zone might be at an advantage over deeper-rooted species. However, Evans and Ehleringer (1994) found that this is not the case for deep-rooted *Chrysothamnus nauseosus* individuals compared with neighboring shallow-rooted species. They conclude that water deep in the soil profile also provides an adequate nitrogen source.

### 3.4. Impacts of Climate Change

#### 3.4.1. Higher Temperature

For most desert regions, the temperature increases predicted in the Greco *et al.* (1994) scenarios are typically in the range of 0.5 to 2.0°C, with greater increases in summer. A rise of 2°C without an increase in precipitation will increase potential evapotranspiration by 0.2 to 2 mm per day (Mabbutt, 1989; Chapter 4). Evapotranspiration may increase due to higher leaf temperatures and higher surface and soil evaporation rates, although the direct effects of higher CO<sub>2</sub> concentrations may partly compensate the tendency for increased transpiration.

Nasrallah and Balling (1993) found an average 0.07°C increase per decade in temperature records for the Middle East from 1945–90 with the greatest increases in spring and the smallest in winter. This increase appears to have been slowed by sulfate emissions and increased by human-induced desertification. Mühlenbruch-Tegen (1992) found no evidence of changes in mean daily temperatures during the past 50 years in South Africa but did find changes in daily minimum and maximum temperatures. These could be accounted for by changes in cloudiness. For example, increased cloud cover may decrease maximum temperatures and increase minimum temperatures by reducing insolation during the day and long-wave reradiation at night. Lane *et al.* (1994) found that from 1901–87, mean annual temperatures increased by 0.12°C per decade in the desert southwest region of the United States, but they could not separate an anthropogenic component from natural variability. Changes in land-use practices can affect surface temperatures. Balling (1988) has suggested that an observed 2.5°C temperature difference across the Mexican/U.S. boundary in the Sonoran desert may be due largely to heavier grazing on the Mexican side, which has led to lower vegetation cover and higher albedo.

Many organisms are already near their tolerance limits, and some may not be able to persist under hotter conditions. Higher

temperatures in arid regions with cold winters are likely to allow spring growth to begin earlier. In some cases this may result in earlier depletion of water reserves accumulated over the cooler winter, leading to an even longer period of potential drought (Skiles and Hanson, 1994).

#### 3.4.2. Rainfall

The Greco *et al.* (1994) scenarios indicate that while some desert regions will receive more rainfall than at present, most will remain extremely arid. In most deserts the predicted additional rainfall is at most only a few centimeters per year, with some models predicting a decrease in many areas. Decreased rainfall is predicted for large parts of the Sahara, northern Arabian, Sonoran, and central and western Asian deserts. Rainfall in the Chihuahuan, southern Arabian, and Atacama deserts is predicted to increase slightly or remain the same, while some of the arid regions of central Australia are predicted to have significant increases in precipitation. The prediction of increased rainfall in Australian desert regions based on the Greco *et al.* (1994) scenarios is contradicted, however, by a general circulation model (GCM) developed by CSIRO in Australia (Whetton *et al.*, 1994). In an alternative approach, Wigley *et al.* (1980) used past warm-weather periods as an indicator of changes in precipitation under global warming. They conclude that precipitation in the arid and desert portions of the United States would decrease under a warmer climate scenario.

The coefficient of annual variation (standard deviation/mean) increases rapidly as mean annual rainfall falls from 300 to 100 mm per year; for sites with 100 mm annual rainfall, the standard deviation can be 0.65 or higher (MacMahon and Wagner, 1985; Fisher, 1994). This means that at sites with 100 mm/yr average rainfall, one year in six will have less than 35 mm of rain. Thus, extreme desert systems already experience wide fluctuations in rainfall and are adapted to coping with sequences of extreme conditions. Initial changes associated with climate change are less likely to create conditions significantly outside the present range of variation.

As CO<sub>2</sub> concentrations increase, plant transpiration is expected to decrease and water-use efficiency to rise (Mooney *et al.*, 1991). Simulation studies for semi-arid and arid sites indicate that water-use efficiency (i.e., carbon fixed per unit water transpired) might increase by up to 50% under a doubled-CO<sub>2</sub> scenario. Even in simulations in which precipitation was assumed to decrease by 10%, standing biomass increased by 15 to 30% (Skiles and Hanson, 1994).

All predictions of changes in precipitation should be treated with caution. None of the current GCMs can reliably predict the distribution of rainfall throughout the year, nor the distribution of rainfall per event. These characteristics are as important as absolute rainfall amounts in the initiation and maintenance of plant growth. Pittock (1988) suggests that in Australian arid areas there may be an increase in the amount of rainfall for a given event. This suggests that pulse species

could benefit in these areas because more of the events may result in moisture sufficient for the completion of their life cycles.

### 3.4.3. *Runoff and Ephemeral Waters*

The impact of changes in temperature and precipitation regimes on runoff and groundwater recharge are complex and depend greatly on the precise timing of events and assumptions about surface conditions. Increases in rainfall intensity, amount per event, and storm clustering will tend to increase runoff in arid and semi-arid ecosystems (Wang and Mayer, 1994; Weltz and Blackburn, 1995). Vegetative cover tends to reduce runoff (Walker, 1991; Weltz and Blackburn, 1995).

A landscape mosaic of runoff and run-on areas is an important component of desert systems. In some deserts with gently sloping surfaces ( $<0.6^\circ$ ), narrow bands of vegetation ("stripes") develop. These bands trap the runoff from wider bands of almost-bare surface upslope of them (White, 1971). At a larger scale, arid lands often are a mosaic of erosion cells, each consisting of erosional, transfer, and sink areas (Pickup, 1985). The sink areas receive the benefits of most of the precipitation falling on the entire cell and accumulate many of the surface nutrients. Both of these situations will amplify any change in runoff patterns (Noble and Burke, 1995).

Lapenis and Shabalova (1994) have suggested that soil structural change may be an important component of climate change because increased precipitation will lead to more organic matter being accumulated in the soil, improved soil field capacity, enhanced moisture availability, and changed runoff patterns. However, their model shows that this process is slow (ca. 400 yr) in desert regions. Fossil aquifers are important water sources in many deserts but will not be affected in the time scales relevant to humans.

Catchment-scale runoff is difficult to predict. An empirical study that predicted catchment-scale runoff from precipitation and temperature suggests that runoff will decrease in arid watersheds in the western United States (Revelle and Waggoner, 1983). However, Idso and Brazel (1984) show that the effect could be reversed if changes in water-use efficiency under increased  $\text{CO}_2$  concentrations were taken into account. Skiles and Hanson (1994) used a more detailed ecosystem model to take into account the seasonal responses of vegetation and found that there was little change, or a decrease, in runoff in simulated semi-arid watersheds. Morassutti (1992) concludes that runoff from three major drainage basins in Australia, including the arid Lake Eyre drainage basin, would increase under scenarios based on the GISS GCM. However, he warns that there are a number of shortcomings in the model and that no trends in precipitation and runoff are discernible from the historical record.

Neilson and Marks (1994) used five GCMs to look at the effect of climate change at the global scale. Their maps suggest that

average annual runoff (in the five GCMs) under doubled- $\text{CO}_2$  scenarios for most of the desert areas of the world will remain the same or increase by 0–25 mm at the most. However, this lack of response may be due to their inclusion of Leaf Area Index (LAI) as a major component in the runoff calculations. In all their desert biomes, LAI is  $<0.1$  or not calculable.

Scattered permanent and ephemeral waters are important for migrating and breeding birds. More than 300,000 birds can reproduce on the ephemeral Lake Eyre in central Australia after a major rainfall event that floods the lake— an event that has occurred only four times in the last 100 years. A population of thousands of egrets has been recorded in ephemeral waters following torrential rainfall in the Peruvian coastal deserts (Caviedes, 1984). Ephemeral water bodies can thus be very important to wetland birds (Kingsford and Porter, 1992) in different desert systems. However, very little is known about the effect of ephemeral events on the overall population dynamics of birds.

### 3.4.4. *Desert Locusts*

The desert locust has a wide distribution in Africa and southwestern Asia, extending over areas with a mean annual precipitation of  $<50$  to 500 mm (Uvarov, 1977). There have been various widely distributed plagues recorded this century (Uvarov, 1977; Pedgley, 1989) that have caused enormous damage. For successful breeding, locusts need warm and moist conditions (Pedgley, 1989); warmer temperatures also hasten their life cycle. Locusts favor ephemeral systems with silty or clayey soil that allows the eggs to survive and provides enough vegetation for the later life stages. However, to reach plague levels they also require meteorological and vegetation conditions that bring previously scattered populations together, allowing them to continue breeding while avoiding natural enemies. Scattered pockets of ephemeral, green vegetation appear to be most suitable.

In the gregarious phase, adult swarms can fly for many days and cover several hundred kilometers, especially in favorable wind conditions (Uvarov, 1977; Pedgley, 1989). Gentle winds allow locusts to take advantage of moist conditions in widely dispersed areas. The most common breeding sites have been recorded during the hot season in the Sahel-Sahara region (Uvarov, 1977). This area has an average annual precipitation of 50–200 mm, and the lush ephemeral vegetation supported by run-on in the wadi systems provides a suitable food source as well as areas suitable for egg-laying.

Other locust species (e.g., the red locust; Walker, 1991) have different behaviors, but in most cases they are best able to take advantage of pulses of moisture availability spread in both space and time. Changes in the frequency of future rainfall events that favor ephemeral or pulse systems could lead to more plagues of locust species. Conversely, in areas that become more continuously wetter or drier, they may be disadvantaged.



### 3.4.5. ENSO and Related Issues

It has been shown that the El Niño Southern Oscillation (ENSO) phenomenon has a wide-ranging effect on regional climates that varies with latitude (Caviedes, 1984). Because major desert areas are driven by anticyclone systems, changes in sea surface temperature have repercussions for the moisture budgets of deserts. For example, El Niño has been associated with droughts in Australia (Nicholls, 1985) and north central Africa (Caviedes, 1984). However, it can also lead to higher precipitation and air temperatures, as in the coastal deserts of Peru and Chile. In these deserts, Caviedes (1984) recorded about a three- to tenfold increase in precipitation and up to a 4°C increase in air temperature during the 1982–83 El Niño. However, the central areas of Peru and the higher elevation areas suffered from drought during the El Niño period. Sea surface temperatures also affect humidity, and some coastal deserts may have more dew and fog associated with ENSO events.

Meehl *et al.* (1993) simulated the effect of ENSO events using a coupled ocean-atmosphere model in combination with a 2 x CO<sub>2</sub> scenario. Their general conclusion is that under doubled CO<sub>2</sub> the ENSO will intensify, and anomalously dry areas will become drier and wet areas will become wetter during ENSO events.

### 3.5. Biogeographical Shifts

Desert regions are known to have undergone significant changes in the past. For example, the northern Sahara changed from Mediterranean flora at about 10,000 yr BP to its present aridity over several thousand years (Evenari, 1985a). Historical records show little shift in desert climates more recently, although vegetation at the margins of desert regions responds dramatically to variations in seasonal rainfall (Tucker *et al.*, 1991). There has also been massive change in some areas due to human activity (see Chapter 4). Long-term studies of desert communities show that they are highly responsive to small changes in the climate regime in which they grow, and in particular to rare events such as unusually moist or dry periods (Hall *et al.*, 1964; Noble, 1977; Noble and Crisp, 1980; Goldberg and Turner, 1986; Turner, 1990).

Monserud *et al.*'s (1993) projection of global vegetation changes in response to a doubled CO<sub>2</sub>-driven climate indicates relatively little change in their desert category (by their definition, about 25% of land surface and thus close to the generally accepted desert and semi-deserts). They found that 82–92% of existing deserts remain so classified under any of the four GCM climates they used. For all vegetation types combined, only 59–66% remain in the same category; deserts were the most stable of the 16 vegetation types they considered.

The Greco *et al.* (1994) scenarios predict moister conditions along the boundaries of only a few deserts. Even if wetter conditions were to prevail, the “greening” of the deserts would often be negated by pressure from the expanding human population and the associated desertification problems (see Chapter 4).

Climate amelioration may lead to increased invasion by species able to disperse widely and possibly to increased fire frequency if the occurrence of ephemeral flora becomes more common. Long-range dispersal mechanisms tend to be rare in plants of the extreme deserts (Ellner and Shmida, 1981; Chambers and MacMahon, 1994). Thus, even if deserts with little plant cover (e.g., the central Sahara) were to become more moist, vegetation may take a long time to respond. In some cases, as in Australia, species (especially birds) that are dependent on ephemeral water bodies may show a population increase.

### 3.6. Mitigation

Despite their extent, extreme deserts store only a small portion of the global C and N pools (much less than 1%); thus, deserts are not a likely sink for excess CO<sub>2</sub>. Some small gains may arise through modified land-use and grazing management practices (see Chapter 2).

### 3.7. Future Needs

There is a lack of information on many aspects of the extreme deserts. The highly pulsed availability of resources and the ephemeral nature of much of the biological activity make them difficult to study. Predictions of the impacts of climate change will depend critically on the precise changes in the seasonality and distribution of rainfall events as much as on the absolute amounts of rainfall.

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